# Development of an advanced ultrasonic phased array for the characterization of thick, reinforced concrete components

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**Jianmin Qu, Novonil Sen (Stevens Institute of Technology)**

## Project Goal

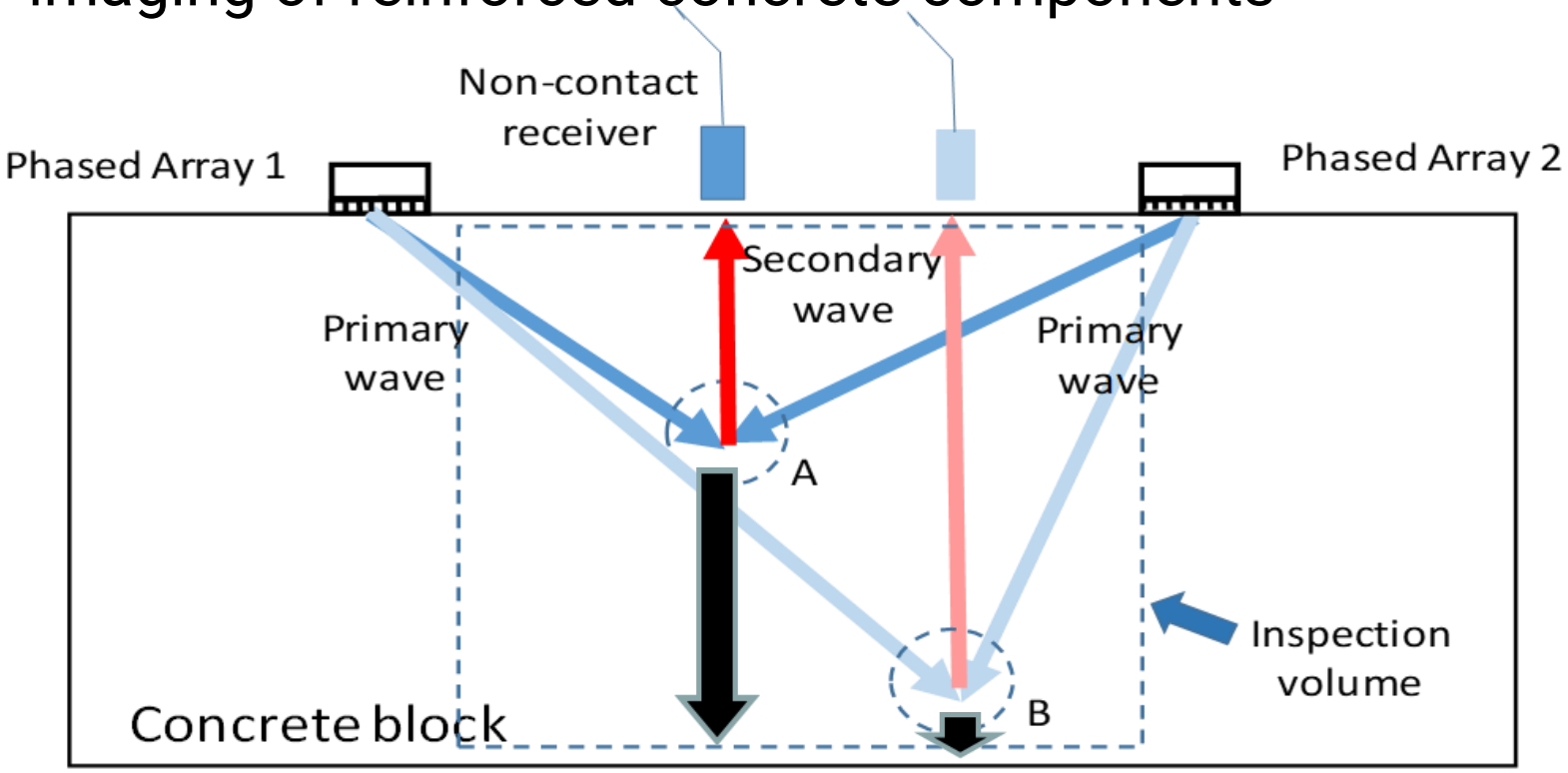
**We are developing an ultrasonic device that uses wave mixing and nonlinear acoustic techniques to quantitatively characterize and image microscale (100 μm) damage in thick, reinforced concrete components.**

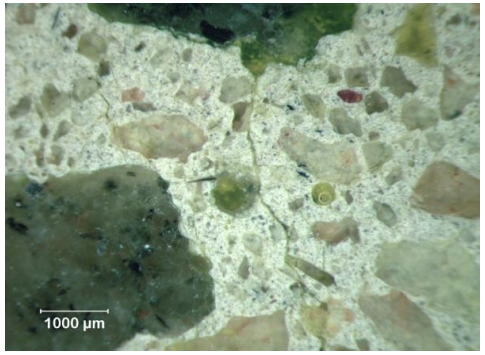
| | |
|---|---|
| Total project cost: | $0.87M |
| Current Q / Total Project Qs | Q9 / Q12 |

**TINA-Cement**
Annual Meeting
October 13 & 14, 2021

# The Concept

- No monitoring/imaging technique exits that can characterize microscale damage
- Increase concrete durability by combining *ultrasonic phased array technology* with *nonlinear wave mixing* and concrete *material modeling* to enable “medical quality” imaging of reinforced concrete components



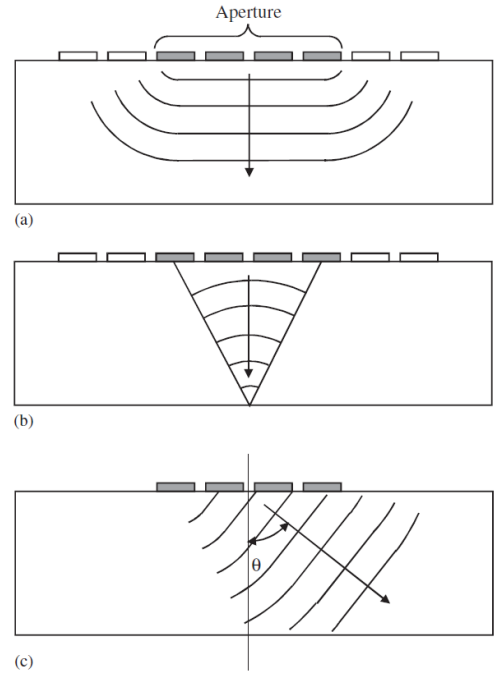
# The Team

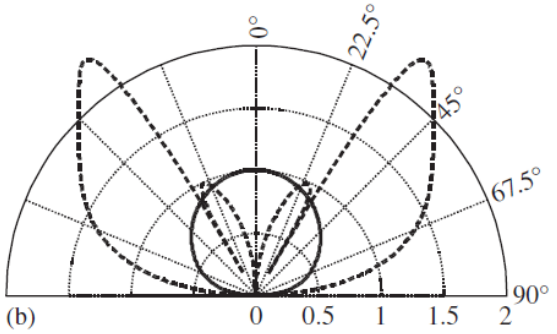
- Team of four faculty co-PIs from Georgia Tech (3) and Stevens (1)
- Laurence Jacobs: linear and nonlinear ultrasound, NDE of concrete
- Kim Kurtis: emerging and novel methods to understand cement- based materials
- Jin-Yeon Kim: measurement and modeling methods for NDE, phased arrays
- Jianmin Qu: ultrasound and micromechanics of concrete

- Jacobs and Kim: development of the phased array device; material modeling
- Qu: computational modeling to optimize wave mixing scheme
- Kurtis: material modeling and development of specimens with known damage

# Project Objectives

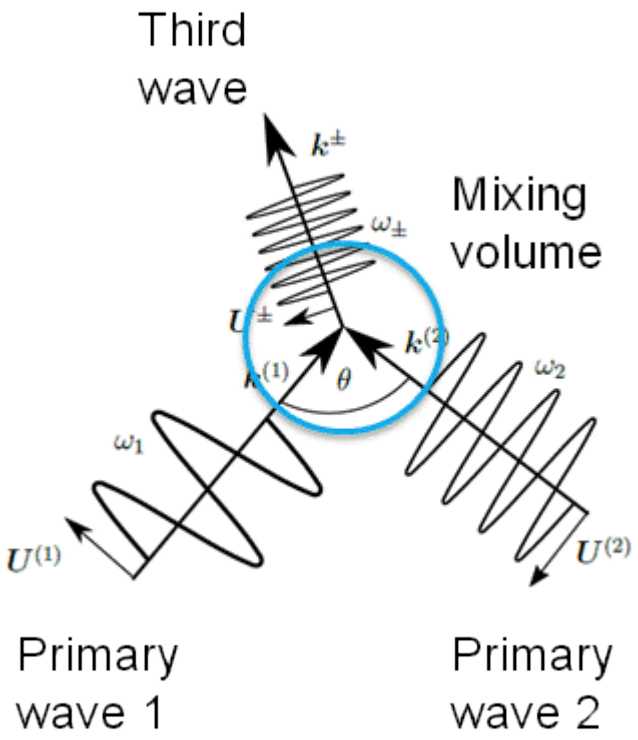
- Established the sensitivity to detect and characterize sub-mm cracks throughout the volume of a 12-inch-thick concrete block, successfully differentiating between damaged and undamaged regions (19 months into a 36-month project, including a 12-month NCE).
- First ever demonstration of the ability to detect and characterize microscale damage in a thick concrete sample, validating the underlying physics of nonlinear wave mixing in concrete.
- Current technical effort on meeting scanning time requirements.
- Final demonstration of forward wave mixing to detect and characterize  microscale (on the order of 1.0 mm) damage in 3-D with a scan time under 30 minutes for a volume of 500 cubic inches for forward propagation.



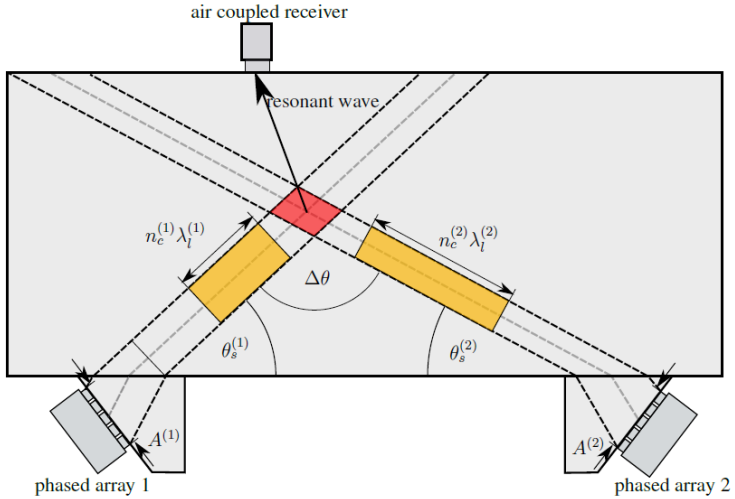



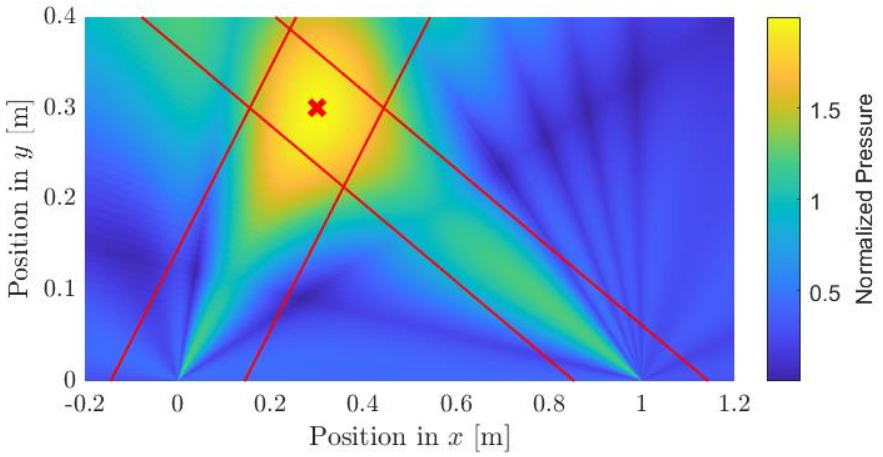
# Device Design Integrates Multiple Technologies

## Nonlinear wave mixing

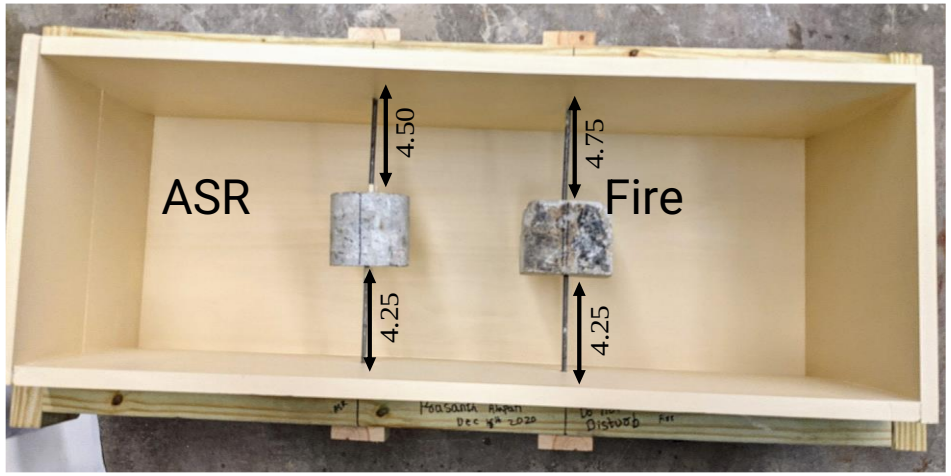


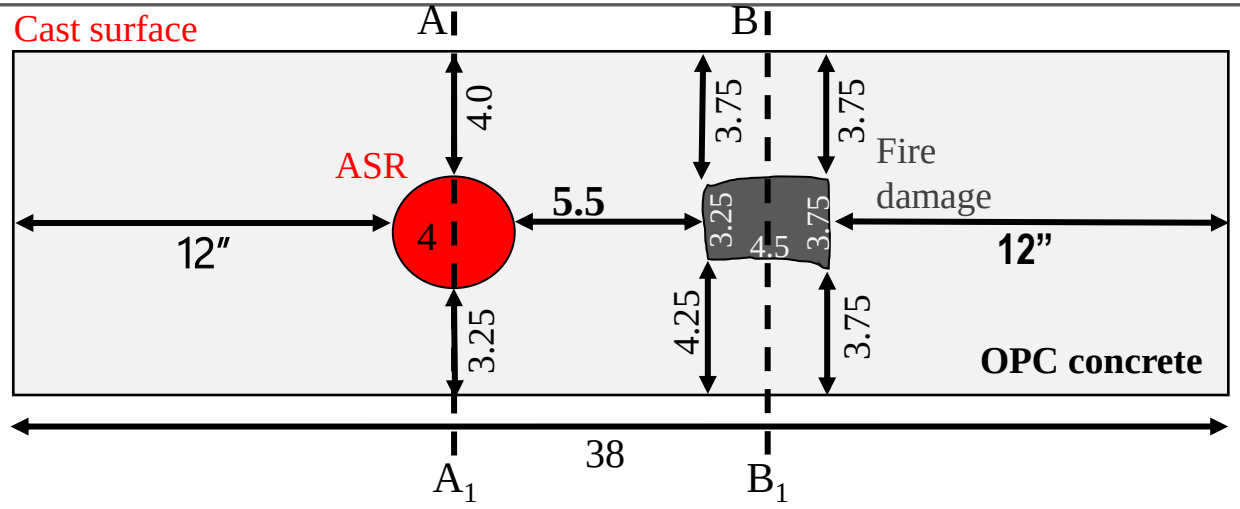

## Focusing with arrays on wedges



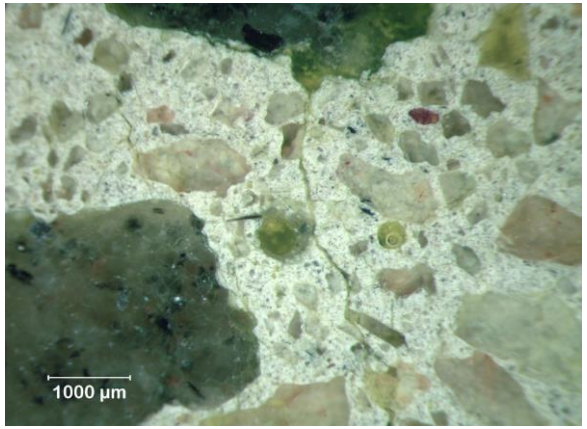
# Blocks with Embedded ASR and Fire Damage




## Fire damage - Petrography

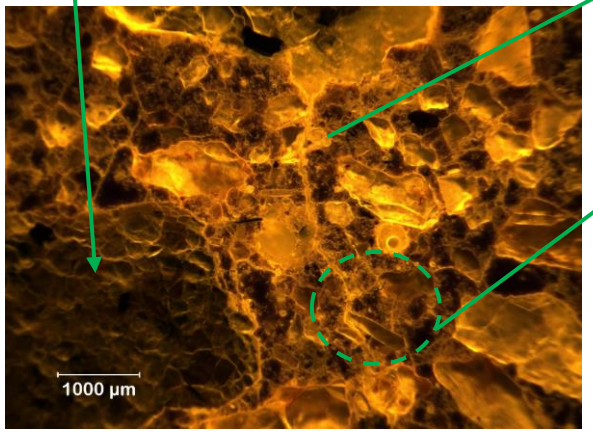
Under visible light

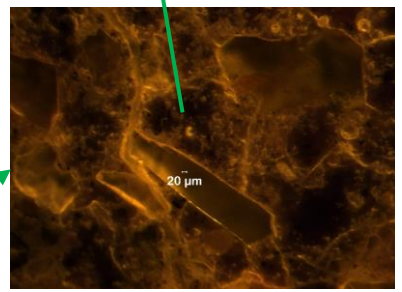



Under short-wave UV light

5-10 µm wide micro cracks within and around the aggregate

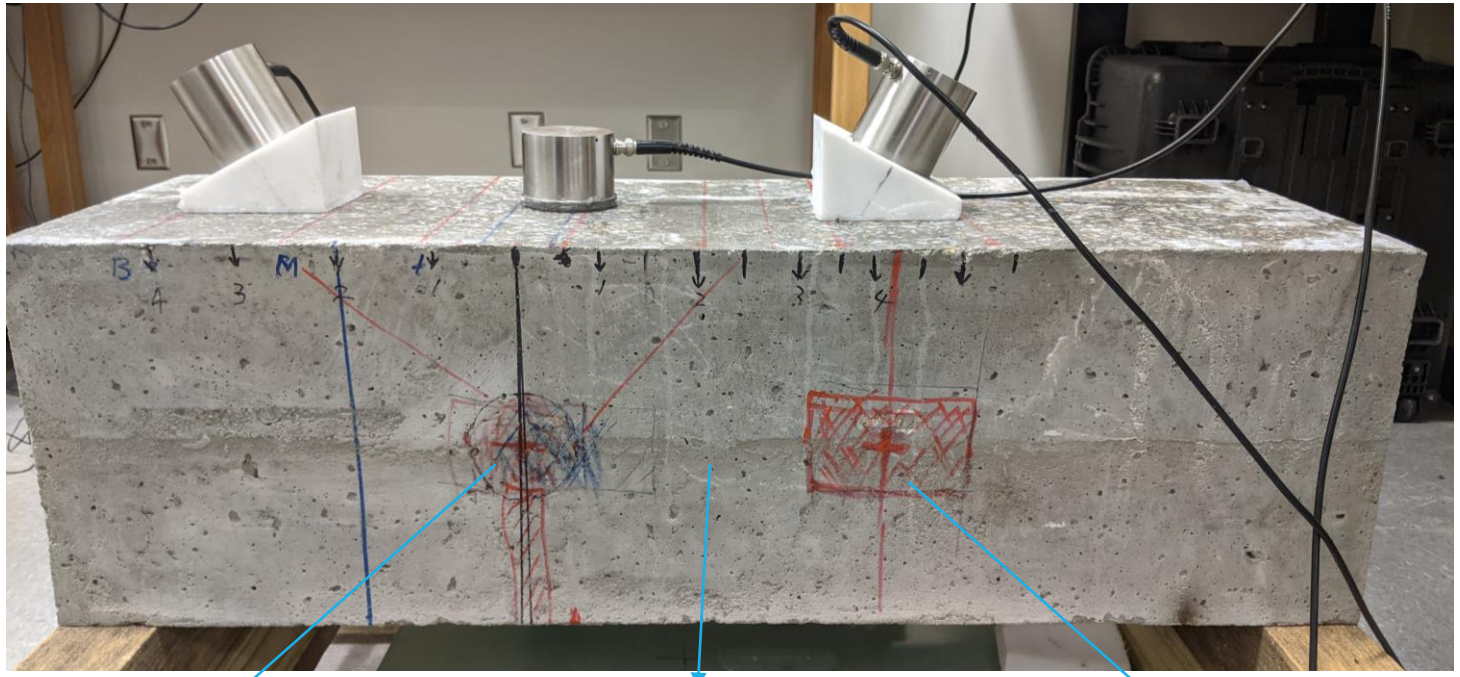
30-50 µm wide long cracks in the paste connecting the aggregates

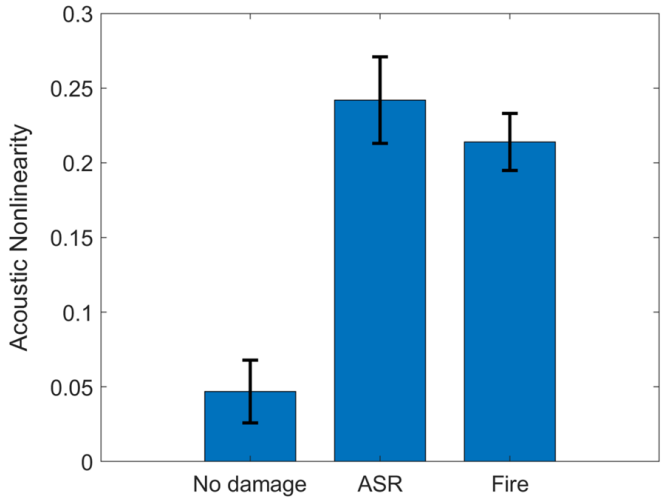


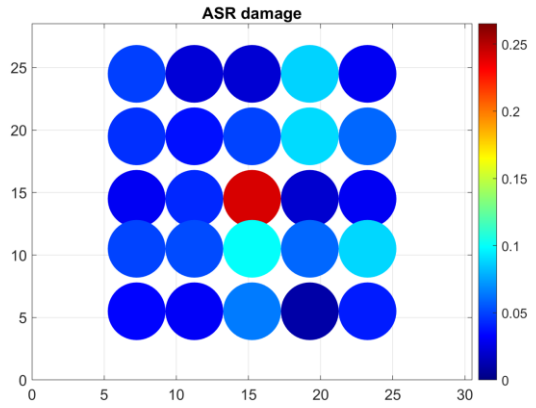



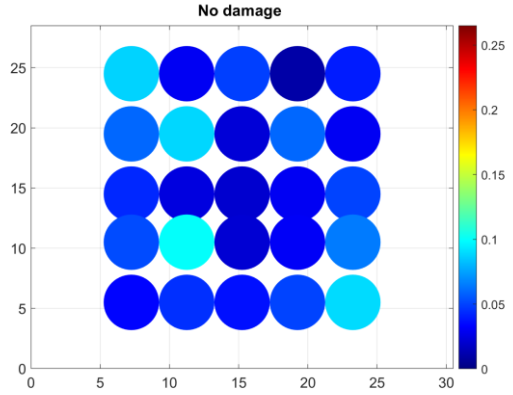
# Scanning of ASR and Fire Damage

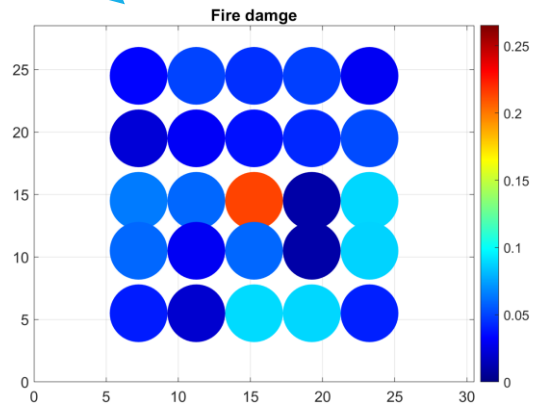
- Imaging of internal damage in concrete beam





# Challenges, Risks and Potential Partnerships

- Main challenge is the inherent physics of the problem: high attenuation due to scattering from the aggregate and material interfaces in the ultrasonic frequency range which we recently overcame with wave mixing approach.
- Current challenge is incorporation of array technology to improve scanning speeds: array (antennae) with required specs is not available and its development is expensive.
- How have you successfully reduced project risk?
  - We are identifying companies to help develop in-house designed array device.
  - Utilizing modeling techniques to refine required specifications.
- Looking for partners in problem identification and next steps in technology development.

# Technology-to-Market

- Device will be a critical tool to help prioritize infrastructure rebuilding, repair and rehabilitation decisions.
- Early detection of microscale damage will increase durability of existing concrete components.
- AASHTO Survey of State DOTs and EPRI partnership to identify applications:
  - Performance-based specifications
  - Warranties for new construction
  - Nuclear power plant license extension

**Improve Concrete Durability**
Highway pavements, Bridge decks, Nuclear power components

**Develop Portable Device:**
Rapid inspection & damage localization (Imaging), Portable device, Early detection

**Combine:**
Array instrumentation, Nonlinear mixing technique, Computational modeling, Concrete material science

# Summary Slide

- Combine ultrasonic phased array technology with an understanding of nonlinear wave propagation in heterogeneous media and concrete material modeling to enable “medical quality” imaging and characterization of thick reinforced concrete components.
- Nonlinear mixing techniques are not wavelength dependent, thus enabling characterization of microscale damage (much smaller than inherent microstructure) in heterogenous concrete material.
- Demonstrated the underlying physics of nonlinear wave mixing in concrete. First ever demonstration of the ability to detect and characterize microscale damage in a thick concrete sample.
- Final deliverable is a device that can detect and characterize microscale (on the order of 1.0 mm) damage in 3-D with a scan time under 30 minutes for a volume of 500 cubic inches.

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